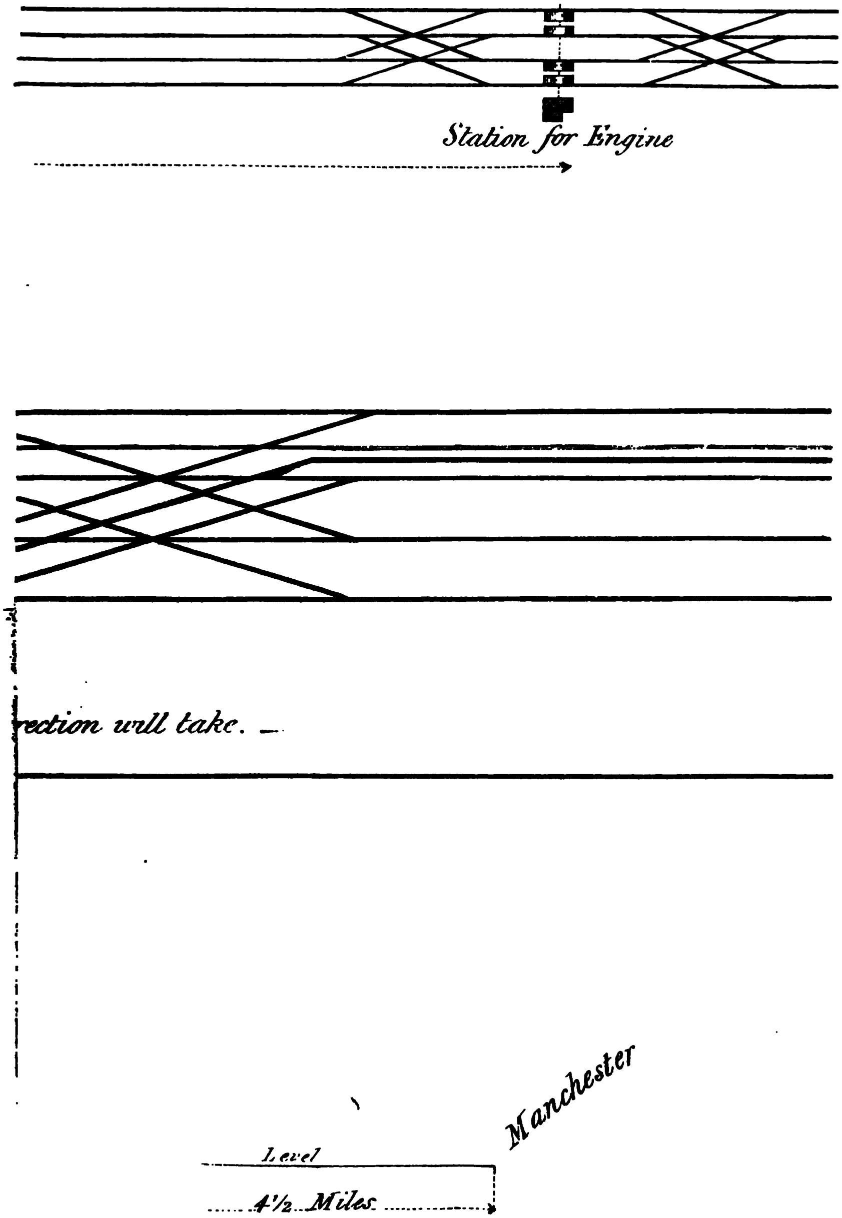
Walker, J.
Liverpool and Manchester Railway.



Station for Engine
rection will take. —
Manchester
Level
4½ Miles

X

LIVERPOOL AND MANCHESTER RAILWAY.

REPORT

TO

THE DIRECTORS

ON THE COMPARATIVE MERITS

OF

LOCO-MOTIVE & FIXED ENGINES,

AS A MOVING POWER.

By JAMES WALKER, F.R.S. L. & E.

CIVIL ENGINEER.

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This Report was written in consequence of a communication from Henry Booth, Esq. Treasurer of the Liverpool and Manchester Railway Company, contained in a letter dated 18th November, 1828, from which the following is an extract.

" The time is arrived when the Directors deem it " necessary to decide on the kind of moving power " to be adopted on the Liverpool and Manchester " Railway. Expecting, as they do, a very large " traffic, perhaps to the extent of 2 or 3,000 tons " per day, to be carried along the line, they have " had little hesitation in determining that some " more efficient power than horses must be used; " but being aware that on the Railways in the North " both Fixed Engines and Loco-motive Engines are " employed, and that their respective merits and " capabilities are variously estimated, they are " anxious to obtain the most correct information on " the subject; and with that view have determined

" to request the combined professional assistance
" of a Civil Engineer and of an experienced maker
" of Steam Engines; and I have accordingly been
" instructed to write to you and to Mr. Rastrick of
" Stourbridge, and to convey to you the request of
" the Directors that you will undertake, on behalf
" of this Company, a journey to Darlington and the
" neighbourhood of Newcastle, to inspect the dif-
" ferent Railways in those districts, and to ascertain,
" by a thorough investigation into the power of the
" Engines, the cost of working them, and their
" actual performance, the comparative merits of the
" two descriptions of moving power."

At a meeting of the Directors at Liverpool, on 12th January, 1829, the following instructions were also delivered:—

" Mr. Walker and Mr. Rastrick are requested, in the first place, to ascertain the comparative expense of conveying Goods on a Railway by Loco-motive Engines and by Fixed Engines.

" But, in addition to this primary object, there are other and very important considerations to be attended to.

" The state and condition of the Road where the different systems are in use, deserves particular regard; and especially how far any injury which

may be done by the Loco-motive to other Roads, is likely to occur to the Liverpool and Manchester.

"The wear and tear of waggons is another point. The cost of repairs under this head, on the Darlington Railway, has been very great—partly, it is said, owing to the Loco-motive Engine. If this be correct, it is important to ascertain whether the evil admits of a *remedy*.

"The quantity of traffic for which it will be expedient to provide the *power of conveyance* may be estimated as follows :—

From Liverpool or towards Manchester.

Daily.	Gross weight, about tons.
1000 tons of goods and merchandize, exclusive of waggons, from Liverpool to Manchester	1500
500 tons cattle, sheep, pigs, &c. that is, the cattle will occupy the room of 500 tons of goods, and the difference in actual weight will not be great *This large quantity may not occur more than two or three days in the week, still it must be provided for, as the conveyance of cattle cannot be delayed.*	750
400 tons of coals, a distance of 12 to 15 miles, say from Kenyon to Manchester	600
800 empty coal waggons, a distance of 8 to 20 miles, say from Liverpool to Whiston, Rainhill and Newton	800
800 passengers from Liverpool to Manchester, occupying about 35 carriages	100
Gross weight towards Manchester....tons	3750

From Manchester or towards Liverpool.

Daily.	Gross weight, about tons.
500 tons of goods, lime, stone, &c. exclusive of waggons	750
300 empty waggons or stages, which will have brought cotton or other goods at 15 cwt. each, say	250
200 empty coal waggons, a distance of 12 to 15 miles, say from Manchester to Kenyon	200
1600 tons of coals, a distance of 8 to 20 miles, say from Newton or Whiston to Liverpool ..	2400
250 empty cattle carriages	250
800 passengers from Manchester to Liverpool, occupying about 35 carriages	100
Gross weight towards Liverpool ....tons	3950

"The Directors are unanimously of opinion, that it is essential to the interests of the concern that the public should be accommodated in every respect, in the best possible manner, so as to leave no room for complaint or dissatisfaction, not only in the direct conveyance from Liverpool to Manchester, but also in taking up and delivering goods or passengers on different parts of the line.

"With reference to the Loco-motive Engine, it will be important to ascertain at what speed it can travel with safety, and with a given pressure of steam, having regard to the *economy of fuel*, an item of expenditure which on either system must unavoidably be so large.

"If Fixed Engines are to be used, can effectual accommodation be afforded to the public, in the way of convenient access to the Railway, for taking up or setting down, branching into, or out of the line, at different parts of the way?

"The comparative *safety*, also, of the two modes, is a point on which the fullest information, and most correct opinion are to be desired.

"Taking into accounts all the circumstances, both as respects *goods* and *passengers*, on the above scale, the goods requiring punctuality of conveyance, and the passengers requiring safety and expedition, can both goods and passengers be conveyed on the two lines of Road at present provided; and if so, by which system of conveyance can the desired object be best attained?

"It will appear by the section that there are

three inclined planes between Liverpool and Manchester, *viz.*

One in the Tunnel,
One at Rainhill,
One at Sutton.

The two former *ascending*, and the latter *descending* towards Manchester; the plane in the Tunnel is 1,970 yards in length, having an inclination of 1 in 48; the other two, 1½ mile long each, being inclined in the ratio of 1 in 96.

"The opinion of Mr. Walker and Mr. Rastrick is requested as to the power of the Engines to be employed at these planes, and as to the best scheme of working them, so as to afford the greatest facility for the transit of the large traffic which must pass over them."

To the Directors of the Liverpool and Manchester Railway Company.

GENTLEMEN,

THE general question submitted for Mr. Rastrick's and my consideration may be shortly stated in these words :

" *What, under all circumstances, is the best description " of moving power to be employed upon the Liverpool and " Manchester Railway?*"

The comparative advantages of the different kinds of power applicable to Rail-roads generally is at the present time a very interesting question, the difficulty and importance of which, as a matter of science, are much increased by the magnitude of your concern, and by the various considerations necessary to be embraced and balanced previously to arriving at any decision that would be useful to you, or consistent with the confidence you have placed in us.

The paper that was handed to us when we attended your meeting at Liverpool, has proved to us that you are fully aware of the points to which I refer. I have endeavoured to view them without prejudice, being assured that as a short time must show the true merits of the various modes of conveyance as applicable to your case and to others, I should, as a professional man, but ill discharge my duty to you, or consult my own interest, by

allowing my judgment to be warped from advising that course, which, from the best information I have been able to collect, it would be advantageous for you to follow. I may here also take leave to say of Mr. Rastrick, that in every thing connected with our inquiry, and the conclusions we have arrived at, I have seen nothing like prejudice for or against any particular system, beyond what arose from his minute attention to the merits of each, and from the result of a very laborious investigation.

Account of Journey.

It may be proper to give you, in a few sentences, an abstract of our proceedings, that you may know how our time has been occupied.

On the 10th January I arrived at Stourbridge, where I was joined by Mr. Rastrick; another reason for my going there being to see a Loco-motive Engine, intended for America, which has just been completed by him, with some improvements and alterations I had not before seen.

On the 13th January, the day after we attended your meeting and received your particular instructions, we proceeded with Mr. Stephenson along the line of your Railway, and on the 14th arrived at Manchester. I think it unnecessary to occupy your time by any report on the progress of your great work, which must be well known to you, further than by remarking, that the works appear to be done in a very substantial manner, and that as respects the strength of the rails, the size of their supports, and the great pains taken in the cuttings and embankments to reduce the inequalities of level, the Liverpool and Manchester Railway is very superior indeed to any thing of the kind that has yet been done.

On the 15th Mr. Stephenson accompanied us to the Bolton Railway, lately executed under his direction.

The principal object of our survey there was a loco-motive Engine made by him upon what he considers the best principle of any he has yet constructed, and the report we have since received from Mr. Sinclair, clerk to the company, to which I shall afterwards have occasion to refer, proves the great power which the Engine is capable of exerting.

On the 16th we arrived at Leeds, Mr. Stephenson having previously left us. Here we examined Mr. Blenkinsop's Engine upon the Middleton Rail-road. We saw it make a journey with 38 waggons, each containing 45 cwt. of coals, which, considering the small size of the Engine, exceeded our expectations, as we were told that a part of the way is level. We therefore requested Mr. Blenkinsop to furnish us with further particulars of expense and performance, which he has kindly and gratuitously done, and has allowed an exact measurement and section of the way to be taken for our use.

The 17th, 18th, 19th and 20th January we passed at Darlington, and upon the Stockton and Darlington Railway. Here was the largest field for observation we had yet seen, there being several loco-motive Engines of different forms and power; horses also are employed upon the same part of the line. Towards the upper end of it there are two inclined planes with stationary Engines. We had therefore the opportunity of seeing various modes of working, and of collecting information, which was liberally given to us, and which was the more to be valued, as neither the very active and intelligent Directors whom we saw nor their Agents appeared to have any object in view, but to advance the prosperity and usefulness of their concern, and to extend the results of their experience for the information of others.

On the 21st we proceeded to Sunderland, and on this and the following day we examined the line of the Hetton Railway, upon the lower part of which the work was,

until within a few years, done by loco-motive, but is now performed by stationary Engines upon the reciprocating principle; the middle part is a series of inclined planes worked by stationary Engines, and upon the mile and half nearest the pits the loco-motive power is still used. From the different Agents upon this Colliery, we received very freely every assistance they could afford us; Mr. Wood, the company's cashier, has, at our request, given us further details, and besides taking an accurate section of the whole road expressly for our use, has furnished us with an account of every particular of expense, and a detailed statement of the various powers and modes of working upon the line.

From Hetton we proceeded on the evening of the 22d to Newcastle, and we remained in that neighbourhood until the 29th. From the 23d till the 26th inclusive, we were employed in arranging the observations of the past week, and in meetings with Mr. Thompson, the Patentee of the reciprocating system by fixed Engines, and with Mr. Wood, the manager of the Killingworth Collieries and author of the well-known treatise upon Rail-roads, both of whom were disposed to forward the object of our inquiry; Mr. Thompson having also allowed us to extract from his private book the details of expense and of work done upon the Brunton and Shields Railway, with much valuable general information on the subject. Thus, although the fall of snow prevented our getting out until the 27th, our time was fully and I trust usefully employed. The whole of the 27th was occupied upon the survey of the Brunton and Shields Road, which was constructed by Mr. Thompson upon his patent plan. The merits of the general principle I shall of course have occasion to discuss hereafter, but with regard to neatness of execution, despatch, and methodical system and arrangement, there is not, I believe, any road at present in use to be compared to this.

The surveys and experiments at Killingworth, in which we were assisted by Mr. Wood, occupied the whole of the 28th, and on the 29th we left Newcastle.

It is but justice to say, that in every quarter where we applied information has been most liberally afforded us, and in some cases before the parties knew who we were or to what our inquiry tended. The Directors, Proprietors, and Agents upon all the Rail-roads which we have visited, have received us courteously, and not only allowed us to inspect their works, but have prepared and furnished us such documents and abstracts as we required: and what is more remarkable, we found but little of that prejudice and strong feeling in favour of one system, which leads to a display of the favourable features and a concealment of the disadvantages on the one side, with a corresponding partial view of the other.

From the time of my return home I have given my almost undivided attention to the subject, in drawing results from our experiments and from the information received while upon the survey.

Having made our separate calculations, Mr. Rastrick and myself met at Oxford on the 20th February, and remained there until the 24th, when we came to general conclusions, in which it was satisfactory to find that there was little or no difference of opinion:—had the time allowed we should either have remained together or met again, and I doubt not have signed the same Report; but knowing from you the importance of not longer delaying the delivery of our decision, we thought it better that each should at once transmit to you his opinion in his own words; and if there be any difference in the items of expense, it is to be ascribed to the consideration we have separately given the question since we separated:—I believe that such difference will be found but trifling.

Your instructions state "*The comparative expense of conveying goods upon a Railway by loco-motive and by fixed Engines*," as the primary object of inquiry.

I shall therefore first consider this subject:—but previously to going into detail, it may be proper to state that certain data are absolutely necessary to form a basis for the comparison. If the quantity of goods be small or uncertain, it would require no calculation to determine that the loco-motive system is the cheaper, because by it you increase the power by an increase of the number of Engines, and can therefore always proportion the power to the demand, while upon the stationary system it is necessary first to form an estimate of the probable trade, and then at once to establish a line of Engines, Ropes, &c. from end to end, that shall be complete and fully equal to it. There is therefore in the loco-motive system an advantage in this respect, that the outlay of capital may at the first be much less than by the other system.

Trade on Line.

You have given us sufficient information to guide us in the extent of power to be provided.

The gross weight from Liverpool or towards Manchester is stated at .... 3750 tons,
And from Manchester or towards Liverpool 3950 „

In the former number are 400 tons of coals and 200 tons of waggons from Kenyon to Manchester, being nearly half the length of the line at the Manchester end, and 800 tons of empty waggons from Liverpool to Whiston, Rainhill and Newton, averaging about half the whole length at the Liverpool end. In the trade towards Liverpool are included 200 tons of empty waggons from Manchester to Kenyon, and 2400 tons of coals and coal-waggons from Newton or Whiston to Liverpool.

This trade is equal to about 2000 tons of goods, or 3000 tons gross, moved in each direction between Liverpool and Manchester daily, which quantity we have therefore taken for the basis of our calculations.

Excepting at Rainhill and Sutton, and at the Liverpool Tunnel, no part of the line rises more than 1 in 800, and as the quantities conveyed in each direction are nearly equal, the assistance received from gravity in the one direction is equal to the retardation caused by it in the other; we have therefore considered the whole line (with the two exceptions stated) as horizontal.

As the stationary system must be adopted in the Liverpool Tunnel, whatever may be done in the other parts of the line, we have entirely excluded it in forming the comparative estimate.

I shall now proceed with the Loco-motive Estimate. **Loco-motive Estimate.**

We assumed the convenient power of each Engine to be 10 horses, including the power necessary to propel itself and its tender. The diameter of the wheels we took at 5 feet, and the strength of the steam in the boiler at from 40 to 50 lbs. per square inch. **Number and Cost of Engines.**

The gross weight of this Engine, with its tender and water, we find to be 10½ tons.

While the Engine is in motion we suppose that its velocity should be 10 miles per hour, to enable it to average 9 miles between the two extreme points; and when the speed of coaches upon the roads is considered, we apprehend that the rate ought not to be less.

An Engine of the above description will be found, by referring to note A, to take 19½ tons gross at 10 miles per hour, or 13 tons of goods and 6½ tons of waggons, and its expense we estimate as follows:—

	£	s.	d.
One Engine will cost	£550	0	0
But to have *five* Engines always in repair six will be necessary, or the capital requisite to provide an Engine always ready for work will be $1\frac{1}{5}$ of one Engine,—add therefore $\frac{1}{5}$ of £550	110	0	0
Together	660	0	0
For a tender, tank, &c. £50, and $\frac{1}{5}$ of 50, being	60	0	0
Making the whole cost of one Engine at work	£720	0	0

Now the average durability of the Engine, when the work is considered, may be taken at 20 years, or at $12\frac{1}{2}$ years purchase.

The annual charge for capital is therefore	£57	12	0			
Less £60 receivable for the old materials at the end of 20 years, which is in present money equal to.	1	16	0			
Leaving annual cost				55	16	0
Add for estimated annual repairs, as per note B........................				107	8	0
And for wages, coal, and other working expenses, as detailed in notes C. and D.				204	0	4
Making the annual cost of each Engine working 312 days				£367	4	4

We have now to ascertain the number of Engines that will be required.

We calculate that each Engine may work, exclusive of stoppages, from 9 to 10 hours per day, at 10 miles per

hour, or it will make three journeys daily between Liverpool and Manchester, taking with it 13 tons of goods, which is the same as 1170 tons conveyed one mile.

The daily traffic being taken at 4000 tons conveyed 30 miles, or 120,000 tons conveyed one mile, will, according to this, require 102 Engines constantly at work.

Our first great item of expense is therefore 102 Engines at £367. 4s. 4d., amounting to £37,456. 2s.

Rainhill and Sutton Planes.

But in this we have allowed nothing for the additional power required at Rainhill and Sutton, the rise of which is 1 in 96. Our idea was that an additional Engine might be employed to assist the others at these planes, but a little consideration showed us our mistake. I am unwilling to confuse my report by introducing calculations into the context; but as it may be important that this point be well understood, I will state the principle in a familiar way. Our calculation of friction upon a level is $\frac{1}{180}$ of the weight moved; but the rise of Rainhill and Sutton being $\frac{1}{96}$, the resistance of gravity is nearly double that by friction. Accurately it is thus:—

2240 lbs. divided by 180 gives for friction of 1 ton	12.44 lbs.
2240 lbs. divided by 96 gives for gravity of 1 ton on rising 1 in 96	23.33 lbs.
The whole resistance to 1 ton on Rainhill is therefore	35.77 lbs.

or say $35\frac{3}{4}$ lbs.

And the resistance to $10\frac{1}{2}$ tons, the weight of Engine, &c. is $375\frac{6}{10}$ lbs.

But the power of the Engine at 10 miles being (by Note A.) 375 lbs., it is evident that an Engine will just move its own weight up the hill at 10 miles per hour, and consequently an additional number of Engines could do no good, as the weight of each would be its load. Either therefore the power of the Engine must be increased, or

the speed diminished, or some other plan be devised for the planes.

The objection to increasing the power is, that it would be forcing the Engine beyond its regular work, which it is desirable to avoid to so great an extent, for it would require two Engines, each 18 horses' power (see note E.), to raise themselves and 13 tons of goods up Rainhill at 10 miles per hour. Whatever may be done for a short length, or for an experiment intended to show what an Engine *can* do, I think it impossible to recommend such a system upon a road which is to unite the various advantages you state.

If again we reduce the speed, say to 5 miles per hour, we shall have half the Engine's power applicable to goods and carriages, the other half being required for its own weight and friction. (See note F.)

In this way, if we suppose the Engine, with 20 tons of goods and waggons, to arrive at the bottom of the planes from Liverpool or Manchester at the rate of 10 miles per hour, it will require another Engine of the same power to go up the plane at 5 miles per hour, and will occupy 18 minutes in ascending. Or, if 8 miles per hour be the standard of travelling, the Engine would then take 27 tons of goods and waggons upon the level (see note G), would require the assistance of another Engine of the same power to ascend the hill, with a speed of 4¼ miles per hour (Note G 2), and would occupy 20 minutes in ascending.

It would consequently be doing an injury to the loco-motive system to apply it to this work, for which it is evidently unfit. However good it may be in itself, it has its limits, and an ascent of 1 in 96 is beyond them, where the length and requisite speed are so great.

We therefore had recourse to the stationary system as the assisting power to the loco-motives upon the planes,

and found that it would be necessary to have two Engines of 50 horses at each end of Rainhill to do the required work, and that the loco-motive Engines also should accompany their load up the hill to assist in taking down the rope, which we found the empty waggons alone could not do with the necessary speed. To give 9 miles clear per hour, the speed of the waggons while in motion upon the planes will require to be 12 miles per hour. The 1½ mile, that is, the length of the plane, will therefore

take	7½ minutes,
and the stoppage for changing, &c.	2½ minutes,
making	10 minutes,

or six journeys per hour, or if ten working hours, say 60 journeys per day; and 3000 tons being to be passed in each direction daily, the load for each journey will be 50 tons, goods and waggons, or say 52 tons, which will require the power stated. (See note H.)

We have now therefore to add the annual cost of the fixed Engines to the sum already stated for the loco-motives, viz. to .... Loco-motive Estimate.

	£	s.	d.	£	s.	d.
tives, viz. to				£37,456	2	0
The expense of stationary Engines, with ropes, &c. as detailed in Note I. is per annum				5,013	6	0
Crossing upon level of way £120, of which the interest is				6	0	0
And for annual expenses of water-stations, as detailed in note K..........				922	10	0
Duplicates of Engines......	£400	0	0			
Duplicates of ropes, 18 tons 17 cwt. 16 lbs. at £51......	961	14	3			
Signals	100	0	0			
	£1461	14	3			
Carried forward				£43,397	18	0

Annual Expense.

	£	s.	d.
Brought forward	£43,397	18	0
This sum (£1461. 14s. 3d.) considered as a necessary additional capital for articles, of which the deterioration is already accounted for, makes at 5 per cent.	73	2	0
The interest of capital and annual expenses of the loco-motive system is therefore	£43,471	0	0

This sum is exclusive of the expense of working the Liverpool Tunnel, which (as was premised) is supposed not to be affected by the plan that may be thought most desirable upon the line generally, and exclusive also of the wear of rails by the Engines travelling upon them.

To reduce this to a rate per ton per mile, we have 4000 tons moved 30 miles per day for 312 days, or 37,440,000 tons moved one mile for £43,471, which is at the rate of .2787, or about $\frac{7}{25}$ of a penny per ton per mile.

Capital requisite.

As the amount of capital necessary under each system is also a proper subject for consideration, I shall, before proceeding to the stationary, state the sum requisite upon the loco-motive plan:—

	£	s.	d.
It comprises 123 Engines & tenders, at £600,	£73,800	0	0
Engines for Rainhill & Sutton (see note I.)	9,190	0	0
Duplicates for same and machinery, as above	400	0	0
Ropes for Rainhill, deducting old (see note I.)...........................	792	0	0
Duplicate ropes, as above	961	14	3
Cost of iron crossings	120	0	0
Signals for Rainhill and Sutton..........	100	0	0
Ten water-stations at £560, (see note K.).	5,600	0	0
So that the requisite capital is....	£90,963	14	3

The expense of the stationary system comes next to be estimated. Stationary Estimate.

Preparatory to this we considered the space between the Liverpool Tunnel and the foot of Rainhill plane, about 6 miles in length, to be divided into 4 spaces, each $1\frac{1}{2}$ mile long; the ascending and descending planes each to form one stage; the 2 miles level upon Rainhill two stages, and the 19 miles, from the foot of the plane to Manchester, to be divided into 12 stages of $1\frac{1}{2}$ mile each, and one stage of one mile nearest to Manchester. The speed of the waggons, while in motion, we supposed 12 miles per hour; consequently the $1\frac{1}{2}$ mile stages would be performed in $7\frac{1}{2}$ minutes, and if $2\frac{1}{2}$ minutes be allowed for stoppages and changing ropes, the rate from one extremity of the line to the other would be 9 miles per hour, which, when allowance is made for taking water, coals, &c., is about the clear rate at which we have estimated the loco-motive Engines. We have supposed the reciprocating plan upon the principle of the Brunton and Shields way to be adopted, and that the weight of the goods and waggons forming the train is 52 tons, as we before calculated for the inclined planes. Number and cost of Engines.

The power to be applied to move this weight upon the level will be 26 horses in each direction;—this we calculated at 30 horses, making thus two 30-horse Engines at each end of the mile and half stages. (See note L.)

The calculation upon the loco-motive system showed that two 50-horse Engines at each end were sufficient to work the Rainhill and Sutton inclined planes; but as the Engines will now, in addition, have to draw the waggons towards them for a mile upon the level, an increase of 10 horses' power has been made to each Engine, making two 60-horse Engines to each station.

An additional power of 30 horses to the Engines at the head of the Liverpool Tunnel also is applied to draw the waggons towards it, and two 12-horse Engines are calculated for the Manchester end, the work of both extremes being in one direction only.

From the descent of the Rainhill planes, and the two stages upon the hill being only one mile long, two Engines of 20 horses each are sufficient in these situations.

	£	s.	d.
The estimate of the two 12-horse Engines at the Manchester end is (per note M.)	£1725	0	0
Fifteen stations with two 30-horse Engines at each, at £3500 (per note N.)........	52,500	0	0
Upon Rainhill and at the foot of the planes, three stations each with two 20-horse Engines, at £2710 (per note O.).	8130	0	0
At the top of the two planes two 60-horse Engines to each (per note P.)	10,000	0	0
At the top of the Liverpool Tunnel 30 horses additional power..............	2000	0	0
Amounting to	74,355	0	0
Pullies for two lines, each $29\frac{3}{4}$ miles long 8 yards distant, No. 13,090 at 15s. including fittings......................	9817	10	0
Extras to foundations of Engines and Engine-houses in Chat Moss	3000	0	0
Making capital for Engines......	£87,172	10	0

Stationary Estimate.

Annual Expense.

	£	s.	d.
Interest at 5 per cent, and depreciation at $1\frac{1}{2}$ per cent. on capital of Engines and Buildings as estimated, or $6\frac{1}{2}$ per cent. in all upon £87,172. 10s.........	£5,666	4	3
Repairs, Coals, and working expenses (see note Q.)	11,257	15	8
Carried forward	£16,923	19	11

Brought forward....	£16,923 19 11
Rope at $\frac{8}{100}$ of a penny per ton per mile, upon 4,000 tons conveyed 27 miles per day, for 312 days....................	11,232 0 0
Ropes for Rainhill and Sutton inclines (same as upon loco-motive system, detailed in note I.)....................	3,315 12 0
Rope for tail-rope on Rainhill and Sutton planes, at $\frac{8}{100}$ of a penny per ton per mile, upon 400 tons conveyed 3 miles per day, for 312 days................	312 0 0
Spare rope—interest upon value (see note R.)	219 15 0
Sundry other expenses and charges as detailed in note S....................	1,291 4 6
Making the total of working the stationary Engines, with interest upon capital.	£33,294 11 5

This sum divided by the number of tons, as in the locomotive system, makes the rate per ton per mile .2134 of a penny.

The capital employed in this case will be as follows :— Capital requisit

Engines as above......................	£87,172 10 0
Duplicates for same (see note S.)	1,354 0 0
Ropes £4,395 (see note R.) and £792 (see note I.)	5,187 0 0
Cast-iron crossings....................	300 0 0
Store ropes £5,336. 16s. 8d. (see note R.) and £961. 14s. 3d. (per loco-motive estimate above)	6,298 11 0
Signals......................... ...	550 0 0
Making total comparative capital	£100,862 1 0

Comparison of Estimates. To bring the whole under one view, I shall here state the results together.

The capital necessary for the various articles stated for the loco-motive system is	£90,963	14	3
And for the stationary	100,862	1	0
Difference in favour of the loco-motive plan	£9,898	6	9

The interest of capital and annual expense of the loco-motive system is	£43,471	0	0
And of the stationary	33,294	11	5
Leaving a difference in favour of the stationary plan of	£10,176	8	7

The rate per ton per mile upon the loco-motive principle is	.2787 of a penny.
And upon the stationary plan	.2134 of a penny.
Making an excess of expense per ton per mile of	.0653 of a penny,

by the loco-motive system, or the comparison of annual expenses is nearly as 7 to 9 in favour of the stationary system.

It is proper here to observe, that as the object of our labours was chiefly a comparative estimate, we have not included any general superintendence or contingent expenses, as these are supposed to be equal upon both principles; nor have I thought it necessary to calculate for the greater trade at the Liverpool end requiring a greater

power of stationary Engines than that at the Manchester end, as this does not affect the aggregate expense. The allotment of power would have made the reports still more complex, and although this will be an important consideration previously to resolving on the power of each particular Engine, the *average* appeared sufficient for our present purpose.

Having thus brought the question of expense to a point, I can readily anticipate a difference of opinion as to the correctness of the result from those who may have previously arrived at different conclusions, and may therefore have been led to prefer the one system as being much cheaper than the other. Opinions as to result.

The principal points of difference are likely to be :—

First—As to the quantity of work which the locomotives are capable of performing.

Second—As to their consumption of fuel.

Third—As to the repairs they may require.

Fourth—As to the friction of the ropes used in the stationary system.

Fifth—As to the expense of ropes per ton of goods conveyed.

I shall therefore state generally the reasons for our conclusions on each of these points.

First—As to the power of the loco-motive Engines. Power of Loco-motives.

We have calculated them at 10 horses, including the power for moving their own weight, which employs nearly the exertion of one horse's strength when going at

followed by an inclination in the opposite direction, in which its work was $7\frac{1}{4}$ horses; upon a level of about a mile, where the way was very much out of repair, it did nearly 11 horses. The Engine was, I think, travelling beyond its average speed, as is usually the case when experiments are being made; but even at this last work it would only carry 16 tons of goods at 10 miles per hour. The Engine was stated to be of 8 horses' power, exclusive of its own weight, say gross power 9 horses, and I believe this to be what it is fairly capable of doing.

Mr. Sinclair's detail of an experiment with the new Engine upon the Bolton way, when with 13 chaldron waggons, each about 73 cwt. it travelled for $1\frac{1}{2}$ mile at $8\frac{8}{10}$ miles per hour upon a rise of 1 in 432, makes the power to have been upon that occasion nearly 24 horses. Were this to be taken as the work which the engine is capable of continuing, it would (see note U.) take 41 tons of goods upon the Liverpool way at 10 miles per hour; but no one estimates the power of the engine at 24 horses, so it is impossible to calculate upon the above as a basis for your work. In the same letter Mr. Sinclair states, that the engine usually takes 7 or 8 waggons, "that number being most convenient," at 6 miles per hour: taking *eight* as the number, this would (see note V.) be the work of an 11-horse Engine, and upon your way is equal to $15\frac{1}{4}$ tons of goods at 10 miles per hour, which I apprehended to be the *practical*, *fair*, *every-day* work of the Engine, and all beyond this is of value only to show how much the Engine *can* do, just as a horse may be made, for a short space, to do twice the work he is capable of continuing without injury. As there is no *lock-up* safety-valve to this Engine, and as the valve is fixed down while the Engine is in motion, it was, I presume, impossible to ascertain the strength of the steam at the time of the experiment to which I have referred.

Mr. Robert Stephenson has reported to us an experi-

ment with Hackworth's Engine, which I prefer, because that Engine has a safety-valve, which, although not quite out of the power of the Engine-man, is stated by Mr. S. to have been at liberty at the time.

It appears by this experiment, that the Engine took $48\frac{3}{4}$ tons of goods 2500 yards, upon a rise of 10 feet in a mile, and returned down, being equal to 5000 yards upon a level, at the rate of $11\frac{2}{10}$ miles per hour, and that the steam was blowing off when the experiment concluded.

I state the preceding as it has been given to us—Hackworth's Engine is undoubtedly the most powerful that has yet been made, as the amount of the tons conveyed by it, compared with the other Engines, proves:—the boiler is longer, with a returned or double flue; there are six wheels, and the weight is increased nearly in the proportion of the power. Mr. Stephenson's report states the consumption of coals to have been $1\frac{6}{10}$ lbs. per ton per mile, which is less than the average of former results, and probably the steam may have been lowered during the experiment, which being for so short a time (about a quarter of an hour) is not better evidence than the regular work of the Engine which has been detailed,—and as the Engine-men are paid per ton for the work they do with the Company's Engines, there is reason to conclude that they work them to the best advantage.

I have reasoned upon the Engines generally in their present state, but it is proper to say that improvements have, since my survey in 1824, been made in them, and that the attention at present bestowed upon the subject will in all probability still do much for them. The Engine made by Mr. Rastrick is different from that by Mr. Hackworth in the form of the flue and otherwise; Mr. Stephenson's is different from both, and every new Engine he makes, differs in some respects from the one preceding it.—Since 1824 the diameter of the wheels has been increased, wrought iron *tire* substituted for cast, spring

safety-valves have been introduced, and the Engine itself is supported upon a spring carriage. I think all these decided and great improvements, and in estimating the question generally it is fair to anticipate others. It is true that improvements in the stationary system may also be expected, but not, I should say, to the same extent.

From the account of work by the Hetton Engines we find that they are doing less than the others, owing, as we have calculated, to the rise in one part of their journey being too great for their advantageous application. By the detail (see note W.) it will be seen that the work of those Engines is upon the Liverpool way equal to only 10 tons of goods at 10 miles per hour.

The slope of the Middleton road is well adapted for loco-motive Engines, descending loaded and ascending empty the average fall being 1 in 440, which makes the load in each direction very nearly the same. Mr. Blenkinsop rates his Engine at 6 horses, and by calculation we find that the work done while in motion, with 30 waggons, is $6\frac{1}{2}$ horses descending and $6\frac{1}{13}$ horses ascending.

Upon the whole, therefore, I am satisfied that the work we have stated for the Engines is as great as ought fairly to be calculated upon,—and I have gone the more into detail that you might be in possession of the principal facts upon which our calculations are founded.

I think it unnecessary to say more respecting the slipping of the wheels, than that it does not appear to form any ground of objection upon your line, when the weight to be taken is considered. The liability to slip is much lessened by the introduction of spring carriages for the Engines. By an experiment we made upon a very irregular part of the Killingworth line it was satisfactorily proved, that with 48 tons of goods and waggons there was no slipping.

Second—As to the consumption of fuel by loco-motive Engines. Consumption of Fuel.

This article is so cheap in most places where loco-motive Engines are in use, that it is not customary to keep any accurate accounts of it, and the objections to a short experiment are evident.

The average of the experiments made at Hetton and Killingworth in January, 1825, gave for one ton of goods conveyed 1 mile upon a level at $4\frac{1}{4}$ miles per hour	2.15 lbs.
Mr. Blenkinsop's account at first made the quantity about 4 lbs., but an explanation since, confirmed by the statement of the Engine-man, reduces the consumption to..	2.70 „
The Hetton account of the present Engines, reduced to a level at about 4 miles per hour, is upwards of	3.00 „
The Hetton account of the Engines when upon the line near Sunderland is	2.00 „
Mr. R. Stephenson's report of the experiment upon the Darlington line, already referred to, at 11 miles per hour	1.60 „

But the account most to be depended upon from the length of time, and the accuracy with which, from its object, we may suppose it was kept, is that which has been furnished to us by Mr. Storey, Surveyor of the Darlington and Stockton line. The Company's view was to ascertain, without the knowledge of the Engine-men, the *actual* consumption of fuel, in the use of which (knowing that the men *pay*, as was before remarked, for the coals they burn) we may reasonably infer that they study economy.

It appears that 298 tons of coals were used by the four

Engines during the months of May and June, 1827, and that the work done in that time was equal to 249,239 tons of coal conveyed one mile upon the way. This is equal to 2.16 lbs. of coal per ton per mile, but as the coal was also employed to bring back the empty waggons, it became necessary to reduce the inclination to a level, and to suppose the Engines to have done work in both directions, which we did, and the result gave 2.8 lbs. of coals per ton of goods per mile. These quantities do not include the fuel required for heating the water at the water stations, and generally it is coal of a quality superior to that which will be used upon the Liverpool road, but the quantity is nearly six times what is necessary for a fixed Engine of the same power. As however the improvements in Mr. Rastrick's and Mr. Hackworth's boilers, to which I have already referred, will cause a saving of fuel, and as Mr. Stephenson's attention is at present directed to the same important subject, we may confidently expect that a reduction of expense on this point will be effected. We therefore fixed upon 2½ lbs. per mile (which may be equal to about 2 lbs. of Newcastle coal), and our calculations are formed upon this standard.

Annual cost of Loco-motives.

Third—As to the *annual cost* of loco-motive Engines.

Any difference of opinion on this point is likely to be confined to the quantum of repair; for as to the original cost and men's wages in working them there can be but little ground for speculation. On the other heads we have formed our own judgment, and we find that the details furnished by Mr. Wood of Hetton and by Mr. Blenkinsop, are both above our estimate; but in this, as in other points, experience will induce a saving. I may instance the use of wrought-iron tire, as well as the great difference

in the quality of this metal: one set of tire had worn out in ten weeks upon the Darlington way, while upon the Killingworth the Engine with which our experiments were made, had a tire which had been twelve months in use, and the effect was scarcely perceptible.

We have supposed that of *six* Engines *five* may be considered as always at work and the sixth under repair, which I do not think is by any means overstating the number necessary.

Fourth—As to the *friction of the ropes* in the stationary system. Friction of Ropes.

Upon this we had some difficulty in obtaining satisfactory data. The friction of a wheel carriage upon a Railroad we have taken at $\frac{1}{180}$ of its weight; but in the present case the number of sheaves to be moved compared with the weight, the irregular surface of the rope, its rigidity or stiffness in winding upon the barrels, and the friction of the drums themselves, make the aggregate of resistance much greater.

If the rope be taken at per yard..............	4	lbs.
A second length of rope upon the drums will be also	4	„
The drums themselves will be equal to........	2.6	„
And the pulleys to..............................	4	„
Making the total weight per yard............	14.6	lbs.

If the friction therefore be taken at $\frac{1}{180}$ of the mass in motion, it will be about $\frac{1}{50}$ of the weight of rope, taking the rope in one direction only or at 4 lbs. per yard $(180 \times 4 \div 14.6 = 50.)$

The results upon the Brunton and Shields way are very

different from each other—In some the estimated power of the Engine is not sufficient to take the load independent of the rope, while in others it leaves a large surplus:—where the former is the case, it is evident that the Engine's power has been under-rated, which we found it generally to be on this line. In two of the planes where empty waggons are taken by gravity, we found (see note X.) the friction of the rope, as nearly as possible, $\frac{1}{22}$ of its weight. These, I think, good data.

Mr. R. Stephenson has reported an experiment upon the Darlington road, by which the friction was $\frac{1}{10}$ of the weight. This was also with the empty descending waggons.

Mr. Thompson's own idea is much under any of the above results.

I think that $\frac{1}{22}$ of the weight of the rope, in one direction, may be taken for its friction, and that of the drums, sheaves, &c.; and if to this be added $\frac{1}{180}$ of the other length of the rope, the result will not be far from the truth, and the strength of the Engines is calculated to be quite equal to this.

Cost of Ropes.

Fifth—As to the *cost of ropes*.

This being a most important item in the fixed system has occupied much of our attention, affecting as it does very materially the relative economy of the two systems. It will be seen by reference to the annual charge that ropes alone amount to upwards of £11,000 per annum, or about one-third of the whole expense.

Upon this subject experience of course is the only guide, and Mr. Thompson's experience is by far the greatest upon the reciprocating system. From an account kept by him, apparently with great accuracy of detail,

" the mean average cost of ropes has been found to be $\frac{51}{1000}$ of a penny," or $\frac{1}{20}$ of a penny nearly. The declination of the way being in the direction of the loaded waggons, and there being in some cases no *tail-rope*, are both favourable to this line as compared with a horizontal road; but as here the waggons are drawn back empty, the cost per ton of goods, as compared with the Liverpool and Manchester line, is increased.

Mr. Story reported to us, that the ropes upon the Brusselton inclined planes cost, by an account kept by him, one farthing per ton upon all the coal conveyed over them. We have by calculation reduced this to a horizontal surface, and find that it would be $\frac{23}{1000}$, or under $\frac{1}{40}$ of a penny per ton of goods per mile, exclusive of the wear of *tail-rope*. (See note Y.)

The reciprocating system being applied on the lower part of the Hetton road, Mr. Wood has informed us, that 301,800 tons of coal were conveyed over a distance of $2\frac{1}{2}$ miles for an expense of £780 in ropes. By reducing this to a level, and to suit our case, we find the cost to be $\frac{13}{100}$ of a penny per ton per mile, which very much exceeds either of the former results. We believe the Coal company pay a price per ton to the rope-maker upon the quantity of goods conveyed.

After fully considering this important subject, in all its bearings, we fixed upon $\frac{8}{100}$ of a penny per ton of goods per mile, dividing it into $\frac{6}{100}$ for the head-rope and $\frac{2}{100}$ for the tail-rope.

In a matter of so great consequence I have thought it proper to be thus particular, at the risk of being tedious; and having now discussed what you very properly call the " primary object," I proceed to the investigation of the other subjects referred to in your instructions to us.

tion, towards it, while in the meantime the two other ropes belonging to the same Engine will be going out as tail-ropes to the two trains that are moving in each direction from it. The journey from Liverpool to Manchester will thus be made in three hours and a half with both goods and passengers. As the stations are a mile and a half apart, the greatest distance to a station can never exceed three quarters of a mile.

If the *switches* or *tongues* of the rails be made with springs, they will act without any interference or care from the attendants being necessary. This will remove in a great degree the evil of crossings, and there being two barrels over each line of way, the motion of the Engine need never be changed.

As the mechanism of this is not easily expressed so as to be intelligible either in words or by a drawing, I have ordered a model to be made, which will, I think, answer the purpose better.

The crossing of roads upon the level of the Railway is more objectionable with the stationary than with the locomotive system. Had the plan been fixed before the levels were formed, this might probably have in many instances been avoided, by making more of the crossings *over* or sinking them *under* the level of the Railway, and with some it may not be too late even now. Mr. Locke has reported to us thirty roads (chiefly for accommodation) upon the level of the Railway in the whole line.

By the Engines working with what are technically called *friction clutches*, or with *friction drums* (by which, in case of stoppage, the Engine goes on without carrying the rope-drum along with it), by having careful men to accompany the trains with powerful brakes, by connecting the head and tail ropes together under the train, by a contrivance instantly to disengage the train from the rope, and by proper signals of approach, any chance of accident to persons or cattle crossing would be very much

lessened; but as the loco-motive Engines can be backed, and the waggons consequently stopped more expeditiously, they are so far safer in this respect.

You inquire particularly as to the "*comparative safety* "*of the two modes*." Safety.

As a general answer I should say that the stationary is the safer, chiefly from the loco-motives being necessarily high pressure Engines, and accompanying the goods or passengers upon the way. I see no reason for changing the opinion I gave you in 1824 of the impropriety of fixing down the safety-valve, without having a lock-up valve out of the Engine-man's power. Within the last year two accidents occurred upon the Darlington way, in each of which a life was lost, and in both cases the safety-valve was fixed down. The Darlington Engines have since had additional spring safety-valves attached to them, by which the danger is much diminished; and Mr. Rastrick has to his Engine fitted an ingenious spring safety-valve, completely beyond the reach of the workman, which will, I doubt not, answer an excellent purpose. In your case, they would be indispensable, for any accident at the outset, attended with loss of life or limb, would seriously prejudice the concern with the public.

All the accidents that I have heard of have happened through the fire-tube bursting, and the steam blowing out the fire-bars, the hot water, &c. at the fire-door. Should you adopt the loco-motive system, the fire-tube should be returned in the boiler, as in Hackworth's Engine, so that the fire-place be in the end of the boiler, farther from the train. By these and the other means commonly in use, and by the careful and frequent examination of the tubes, I think there could be but little dan-

going at different speeds, or in case of any stoppage or accident upon either of the main lines.

> Upon the consideration of the question in every point of view, taking the two lines of road as now forming, and having reference to *economy*, *despatch*, *safety* and *convenience*, our opinion is, that if it be resolved to make the Liverpool and Manchester Railway complete at once, so as to accommodate the traffic stated in your instructions, or a quantity approaching to it, the *stationary reciprocating* system is the *best;* but that if any circumstances should induce you to proceed by degrees and to proportion the power of conveyance to the demand, then we recommend *loco-motive* Engines upon the line generally, and *two fixed* Engines upon *Rainhill* and *Sutton* planes, to draw up the loco-motive Engines, as well as the goods and carriages.

Should the latter plan be adopted, you would of course only order such a number of Engines as you might see occasion for, both on account of saving expense, and to enable you to take advantage of the improvements which might be made; with a view to encourage which, and to draw the attention of Engine-makers to the subject, something in the way of a premium, or an assurance of preference, might be held out to the person whose Engine should, upon experience, be found to answer the best. The Rainhill Engines would at the same time enable you to judge of the comparative advantages of the two systems, and if upon any occasion the trade should get beyond the supply of *loco-motives*, the *horse* might form a temporary substitute.

About three miles of the Brunton and Shields way are wrought by horses, the expense of which Mr. Thompson finds to be equal to $\frac{45}{100}$ of a penny per ton of goods per Horse Power.

mile upon a level road, and my calculation makes it $\frac{43}{100}$ of a penny; but this is at the animal's best speed, or about $2\frac{1}{2}$ miles per hour.

The Darlington company pay a halfpenny per ton of coal per mile, for the horse hire and driver; consequently, they pay 10d. for every ton of coal that is led to Stockton, a distance of 20 miles, but this also includes the bringing back of the empty waggons. The loco-motive Engine-men find coals, oil, tallow, hemp, oil for the waggons, and their firemen or assistants, for $\frac{1}{4}$d. per ton per mile. Now if finding and repairing the Engines be estimated at $\frac{1}{8}$d. (which appeared to be the opinion of the company's agents), there is a saving of $\frac{1}{8}$ of a penny per ton per mile, by the loco-motive Engines, under this head; but I apprehend that the damage to the rails upon the Darlington is greater than the expense of repairing the horse-track, and that the horse labour would be as cheap to this company. This, however (like the calculation for the Brunton way above), is taking the horse at his most advantageous speed.

At an increased speed the muscular exertion is so great that the effect of the horse is much reduced, and the expense is so much increased, that if at $2\frac{1}{2}$ miles per hour the cost per ton per mile be taken at $\frac{45}{100}$ of a penny, it cannot at the speed of 6 miles, be taken at less than three times that amount, or $1\frac{1}{3}$d, and at 10 miles per hour, at not less than 3d. per ton per mile. (See Note Z.)

Horse power for heavy goods at high speeds is therefore quite out of the question for a traffic such as you expect, while exclusive of the friction of the rope and drums, the stationary Engine costs the same price per ton of goods and waggons per mile at all practicable speeds, and the loco-motive varies from this only so far as its own weight forms a part of the *load*. If in one day the loco-motive be so loaded as to have performed a full day's work, and have travelled only 33 miles, and if on another day it has

moved over 66 miles, twice the quantity of power will have been employed to overcome the Engine's own friction on the second day that was on the first. The power exerted in every instant of time to overcome the friction being proportional to the space passed over, the Engine will, at a great speed, have less of her power to apply to goods. Thus, if an 8-horse Engine at 3¼ miles per hour take 41¼ tons, it will at the rate of 8 miles take only 13½ tons; but as it will travel a greater distance at the rate of 8 miles, the expense per ton per mile is by no means proportional to the decrease of load. The expense per ton per mile being at 3¼ miles per hour equal to 3, that at 8 miles is about 4.

I have thought it proper to say thus much, to give a general idea of the laws of the two steam systems and of animal labour.

The only remaining question respects the Liverpool Tunnel, the system for working which will be the same, whatever be the plan for the other part of the line, with this difference only, that with the stationary principle throughout the line, the Engines that work the plane in the Tunnel will require an addition of power to draw the waggons for 1½ mile towards the Tunnel. If the locomotives be unfit for the Rainhill and Sutton planes, they are of course more so for this Tunnel. I apprehend there can be no difference of opinion as to the kind of power to be employed here. We recommend two 60-horse Engines, the speed 10 miles per hour, the gravity of the *descending* waggons being used to assist the *ascending*. (See Note A. 2.) Liverpool Tunnel.

Ground required.

In conclusion, I beg to add, that when so great a trade as 50 tons of goods and waggons despatched every ten minutes is contemplated, the Company would do well to embrace any opportunity that may offer for giving them an ample space of ground, particularly at the top and bottom of the Liverpool Tunnel, where they appear at present much confined. A considerable area will be required for the waggons to prevent any delay in starting from the two extreme points, and upon this much of the desired punctuality and despatch must necessarily depend.

I am, Gentlemen,

Your most obedient Servant,

J. WALKER.

Lime-House, London,

7th March, 1829.

NOTES OF REFERENCE

TO

THE FOREGOING REPORT.

NOTE A. Load of Loco-motive Engine.

Horses' power for calculation of Engines, 33,000 lbs. per minute, or 150 lbs. raised 220 feet per minute, or at $2\frac{1}{2}$ miles per hour; therefore $150 \div 4 = 37.5$ lbs. = horse's power at 10 miles per hour, or 375 lbs. for 10 horses, equal to friction of 30 tons (taking friction at $\frac{1}{180}$ of weight), say then .... 30 tons.

Deduct weight of Engine, Tender and Water .... $10\frac{1}{2}$ „

Leaves for goods and waggons .... $19\frac{1}{2}$ tons.

Or 13 tons of goods, and $6\frac{1}{2}$ tons of waggons.

NOTE B. Estimate of Repairs, &c. of Loco-motive Engine.

	£	s.	d.
A Tube and Chimney-breast every three years, or annually	£12	10	0
Occasional repairs to Boilers	3	0	0
New Chimney each year, and deduct old	7	10	0
Set of Chimney-bars every two months	6	0	0
Axles and Brasses, one set annually	10	0	0
Wheels	36	0	0
Tender, Carriage and Tank	2	10	0
Small Repairs	12	0	0
	89	10	0
Add one-fifth for spare Engine	17	18	0
Total	£107	8	0

NOTE C. Coal for each Loco-motive Engine.

A 10-horse Engine will take 13 tons of goods 10 miles per hour, and will go between Liverpool and Manchester three times each day— $30 \times 3 = 90$ miles per day, and $13 \times 90 = 1170$ tons of goods 1 mile per day by each Engine. 1170 tons of goods at $2\frac{1}{2}$ lbs. of coal per ton per mile = 2925 lbs. of coal per day, and $2925 \times 312 = 912{,}600$ lbs. per year = $380\frac{1}{4}$ tons, or say 382 tons of coal for each loco-motive Engine per year.

NOTE D. Account of Working Expenses.

Engine-man's Wages, at 21s. per week	£54	12	0
Boy to assist	26	0	0
Coal (Note C.) 382 tons at 5s. 10d. (price given us)	111	8	4
Grease, Oil, Hemp, &c.	12	0	0
Total	£204	0	4

NOTE E. Loco-motive Engines for Rainhill and Sutton inclined planes, at 10 miles per hour.

10-horse Engine upon these planes can draw $10\frac{1}{2}$ tons at 10 miles per hour (by text of Report).

13 tons of goods = $19\frac{1}{2}$ tons of goods and waggons.

If $10\frac{1}{2}$ tons, weight of one Engine and Tender require . . 10-horse power,

Another Engine without tank or water carriage, $8\frac{1}{2}$ tons, will require . . . . 8 horses;

And in the same proportion, $19\frac{1}{2}$ tons of goods and carriages will require . . . . $18\frac{1}{2}$ horses.

Total power . . . . $36\frac{1}{2}$ horses.

NOTE F. Loco-motive Engines for Rainhill and Sutton, at five miles per hour.

Horse's power at 5 miles = $150 \div 2 = 75$ lbs., or for 10 horses,	750 lbs.
Deduct gravity and friction of carriage	375 „
Leaves applicable to load	375 lbs.

375 lbs. $\div$ 35.77 lbs (resistance of one ton by text) gives gross $10\frac{1}{2}$ tons,

Or goods only $7\frac{1}{2}$ tons.

NOTE G. Loco-motive Engine on level at eight miles per hour.

Horse power at 8 miles $= 150 \times 2\frac{1}{2} \div 8 = 47$ lbs., or for 10 horses, 470 lbs.

Then $470 \div 12\frac{1}{2}$ (resistance of one ton) gives	37.6 tons.
Deduct Engine, &c.	10.5 „
Leaves goods and waggons	27.1 tons.

Or goods 18 tons, and waggons 9 tons.

NOTE G 2. Time of Loco-motive Engine on inclined Planes.

$27 + 10\frac{1}{2} + 8\frac{1}{2} = 46$ tons = weight of load and two 10-horse Engines (Notes G. & E).

$35.77 \times 46 = 1645$ lbs. = total resistance to 20 horses.

$1645 \div 20 = 82$ lbs. = exertion for each horse.

82 lbs. : 150 lbs. :: $2\frac{1}{2}$ miles : $4\frac{1}{2}$ miles per hour.

NOTE H. Fixed Engines for Rainhill and Sutton.

52 tons or 116,480 lbs. $\div$ 96, the rise of the plane, gives for gravity	1213 lbs.
Add 116,480 lbs. $\div$ 180, for friction	647 „
Together	1860 lbs.
Friction of rope $= \frac{1}{22}$ of its weight, or of 10,560 lbs	480 „
Gravity of rope $= \frac{1}{96}$ of its weight	110 „
	2450 lbs.

2450 lbs. $\div$ 31 lbs. (power of horse at 12 miles) = 80 horses, or allowing for surplus power, say 2 Engines each 50 horses' power.

NOTE I. Expense of Fixed Engines upon Rainhill and Sutton.

Two 50-horse Engines for Rainhill, at £1500 each	£3000
Machinery and drum-barrels	300
Engine-house and chimney	600
Engine-man's dwelling	100
Reservoir or well for water	100
Pulleys, No. 330 for each line, or 660 for the two lines at 15s.	495
	£4595

	£	s.	d.	£	s.	d.
Interest on £4595 at 5 per cent........................				£229	13	6
General depreciation at 1½ per cent....................				69	0	0
Boilers, say 3 to last 12 years, difference of value £24 per ton=£480 to be expended at the end of 12 years, equal to an annual expense of				13	4	0
Fire bars annually				5	0	0
Repairs to Engine and Machinery				35	0	0
Oil, Tallow, Hemp, &c				20	0	0
Wear and tear of Pulleys				25	0	0
Coals equal to 80 horses working 12 hours per day, allow 15 lbs. of small coal per horse per hour, which gives for 312 days 1872 tons, at 2s. 6d. (price given to us)....	£234	0	0			
Add coal for raising steam, 377 tons at 2s. 6d.	47	2	6			
				281	2	6
Wages as follow:—						
Engine-man	£54	12	0			
Fireman	39	0	0			
Brakeman............................	39	0	0			
				132	12	0
Men to grease sheaves, one man to both planes, say for each plane..				19	10	0
Oil, 150 gallons at 2s. 6d.				18	15	0
				848	17	0
Similar Engine and expense for the other plane				848	17	0
				1697	14	0
Ropes; 4 ropes for these two inclines, each 2640 yards long, 5½ inches circumference= 4 lbs. to one yard, each rope therefore 94 cwt. 1 qr. 4 lbs. and the 4 ropes 18 tons 17 cwt. 16 lbs. which at £42 per ton (being £51 less £9 for old ropes), gives £792..............						
Interest upon £792 capital at 5 per cent.....	£39	12	0			
Annual expense of ropes being for 4000 tons passed 3 miles daily for 312 days at $\frac{7}{100}$ of a penny per ton per mile upon a level, and adding for slope of 1 in 96, being nearly three times the wear upon a level	3276	0	0			
				3315	12	0
Making total..........				£5013	6	0

NOTE K. Expense of Water Stations.

A two-horse power Engine to each station	£200
Pumps, kettle and machinery	100
Engine-house and cistern	150
Cottage for man	60
Well or pond	50
	£560

Interest and depreciation on £560 at 6½ per cent	£42	0	0
Wear of boiler and bars, grease, &c	5	0	0
Coal for Engine, kettle, &c.—50 tons at 2s. 6d	6	5	0
Engine-man	39	0	0
	£92	5	0

10 Stations at £92. 5s. each, £922. 10s.

NOTE L. Power of Stationary Engines.

Friction of 52 tons = 116,480 lbs. ÷ 180 =	647 lbs.
Friction of ropes, sheaves and drums = $\frac{1}{22}$ of weight, say of 3,400 lbs. (being weight of 1½ mile of 3½ inch rope), equal to	155 lbs.
Friction of rope upon barrel	13 lbs.
	815 lbs.

Power of horse at 12 miles = 150 × 2½ ÷ 12 = 31 lbs. then, 815 ÷ 31 = 26 horses, or say, allowing for spare strength, 30 horses.

NOTE M. Expense of Fixed Engines at Manchester end.

Two 12-horse Engines, each £500	£1000
Machinery and drum-barrels	200
Engine-house and chimney	400
Dwelling-house	75
Well and pump, or pool for water	50
	£1725

NOTE N. Expense of Fixed Engines upon 1½ mile stages.

Two 30-horse Engines, each £1200	£2400
Machinery, drums, &c.	400
Engine-house and chimney	500
Dwelling-house	100
Well or pool for water	100
	£3500

Fifteen Engines at £3500 = £52,500.

NOTE O. Expense of Fixed Engines for middle of the 2 miles level, and at the foot of each plane.

Two 20-horse Engines, each £900	£1800
Machinery and drums	300
Engine-house and chimney	450
Dwelling-house	75
Well or pond	85
	£2710

Three Engines at £2710=£8130.

NOTE P. Expense of Fixed Engines to Work Planes.

Two 60-horse Engines, each £1800	£3600
Machinery, drums, &c.	500
Engine-house and chimney	700
Dwelling-house	100
Well and pond	100
	£5000

Two Engines at £5000=£10,000.

NOTE Q. Estimate of Repairs & Working expenses of Stationary Engines.

	£	s.	d.
Repair to boilers of Engines for the power of 1354 horses, taken in the proportion of £13. 4s. to 100 horses	£178	14	6
Fire bars taken in like proportion at £5.	67	14	0
Repairs to Engines and Machinery, at 7s. for one horse's power..	473	18	0
Oil, Tallow, Hemp, &c. at 4s. for one horse's power	270	16	0
Coal in proportion to former estimate for 100-horse Engine=18.72 tons per horse, or $25,346\frac{88}{100}$ tons per annum, exclusive of coal for raising steam (Note S.) at 2s. 6d. .	3168	7	2

Men required as follows:—

	Manchester Engine.	Fifteen 1¼ mile Engines.	Three 20-horse Engines.	Two 60-horse Engines.	Liverpool Tunnel extra.	Total.			£	s.
Engine-men.	2	30	6	4	1	= 43	at £54	12 =	£2347	16
Bankmen....	2	30	6	4	2	= 44	„ 39	0 =	1716	0
Brakemen ..	1	30	6	4	1	= 42	„ 39	0 =	1638	0
Assistants ..	0	15	3	2	1	= 21	„ 39	0 =	819	0
10 men to oil pulleys, at £39									390	0

	£	s.	d.
	6910	16	0
Oil, 30 miles at 50 gallons per mile=1500 gallons at 2s. 6d.	187	10	0
	£11,257	15	8

NOTE R. Capital and Interest upon Rope.

	£	s.	d.
114 miles of 3½-inch rope at 1¾ lb. per yard, is 104 tons, 12 cwt. 3 qrs. 14 lbs. at £51 per ton for new	£5336	16	8
Less £9 per ton for old	941	16	8
	£4395	0	0

Interest on £4395 at 5 per cent. = £219 15 0.

NOTE S. Sundry Expenses and Charges of Stationary system.

	£	s.	d.
30 crossings by iron pipes, capital £300 at 5 per cent	£15	0	0
Coal each morning for raising steam, 28 lbs. per horse per day for 1354 horses for 312 days	616	2	6
Wear of pulleys, in proportion of £25 for 3 miles........	250	0	0
Interest upon duplicates, say 1354 horses at £1 = £ 1354.	67	14	0
Ropes, capital as above (note R)..£5336 16 8			
For planes per loco-motive estimate 961 14 3			
6298 10 11 at 5 per ct.=	314	18	0
Interest upon signals, £550 at 5 per cent..............	27	10	0
	£1291	4	6

Note T. Work of Darlington Loco-motive Engines reduced to a level surface, the rise of this way *averaging* 1 *in* 246.

Hackworth's Engine.

This Engine's draught, as stated in the text, is equal to the following upon a level surface:—

	Summer.			*Winter.*		
	5 *miles.*	8 *miles.*	10 *miles.*	5 *miles.*	8 *miles.*	10 *m.*
Goods	46.75	25.00	17.75	39.90	21.00	14.30
Waggons	23.10	12.50	8.80	19.80	10.20	7.20
Engine and Tender	16.50	16.50	16.50	16.50	16.50	16.50
Tons	86.35	54.00	43.05	76.20	47.70	38.00

Smaller Engines.

	Summer.			*Winter.*		
	5 *miles.*	8 *miles.*	10 *miles.*	5 *miles.*	8 *miles.*	10 *m.*
Goods	34.66	18.66	13.33	28.75	15.00	10.33
Waggons	17.33	9.33	6.66	14.50	7.50	5.20
Engine and Tender	12.00	12.00	12.00	12.00	12.00	12.00
Tons	64.00	40.00	32.00	55.25	34.50	27.53

Note U. Experiment with Loco-motive Engine upon Bolton Railway, reported by Mr. Sinclair.

	Cwt.	Lbs.
Weight of one waggon	30	0
Weight of its load	42	96
	72	96

72 cwt. 96 lbs. = 8160 lbs. × 13 waggons = 106,080 lbs.

Add Engine = 10 tons, 13 cwt. .... 23,856 „

Mass moved .... 129,936 lbs.

129,936 lbs. ÷ 180 = 722 lbs. = friction.
129,936 lbs. ÷ 432 = 301 lbs. = gravity.

1023 lbs.

1023 lbs. × 8.8 miles = 902.44 lbs. ÷ 12.5 lbs. (Frict. of 1 Ton.) = 72.2 tons,

Deduct Engine.... 10.5 „

Gross...... 61.7 tons,

Deduct ½ for waggons...... 20.5 „

Goods.... 40.2 tons, or say 41 tons.

NOTE V. Bolton Loco-motive Engine, with 8 waggons, at 6 miles per hour.

By note U. above, one load gross = 8160 lbs. which
×8 waggons = ... 65,280 lbs.
Add Engine .... 23,856 lbs.

Mass moved .... 89,136 lbs.

89,136 lbs. ÷ 180 = 495 lbs. = friction.
89,136 lbs. ÷ 432 = 206 lbs. = gravity.

701 lbs. = resistance.

701 lbs. × 6 miles ÷ 10 miles = 420 lbs. ÷ 12.5 lbs. (Frict. of 1 Ton.) = 33.6 tons
Deduct Engine .... 10.6 tons

Gross .... 23 0 tons
Deduct ⅓ for waggons .... 7.6 „

Goods .... 15.3 tons, or 15⅓ tons

NOTE W. Hetton Loco-motive Engines, by Mr. Wood's Report.

In 30.00 chains falls .... 14 ft. 0 in. which is equal to 1 in 141
72.45 „ .... 9 „ 3½ „ „ 1 in 514

In 102.45 chains falls .... 23 ft. 3½ in. which is equal to 1 in 287

In summer takes down 16 waggons containing 848 cwt. of coal
Add waggon .... 512 „
Engine, &c. .... 210 „

Together .. 1570 cwt.

20 journeys = 51 miles per day, say 4¼ miles per hour for 12 hours, or, allowing for stoppages, 5 miles per hour.

1570 cwt. = 175,840 lbs. ÷ 180 = 977 lbs. = friction.
Deduct ...... 175,840 „ ÷ 287 = 612 „ = gravity.

Resistance descending 365 lbs. ÷ 12½ = 29 tons, load down

512 + 210 = 722 cwt. = 80,864 lbs. ÷ 180 = 449 lbs. = friction.
Add 80,864 „ ÷ 287 = 282 „ = gravity.

Resistance ascending 731 lbs. ÷ 12½ = 58½ tons, load up

87½ tons.

Divide by 2 for average or on level .. 43¾ tons.

But as the rise on part of the road is not favourable, say the work on a level is $50\frac{1}{2}$ tons at 5 miles per hour.

Upon this basis the work at different speeds is as follows:—

	5 miles.	*8 miles.*	*10 miles.*
Goods	$23\frac{1}{4}$	14	$9\frac{9}{10}$
Waggons	$16\frac{3}{4}$	7	$4\frac{9}{10}$
Engine........	$10\frac{1}{2}$	$10\frac{1}{2}$	$10\frac{1}{2}$
	$50\frac{1}{2}$	$31\frac{1}{2}$	$25\frac{1}{4}$

Now $50\frac{1}{2}$ tons at 5 miles = 101 tons at $2\frac{1}{2}$ miles, and $101 \div 12 = 8\frac{5}{12}$ horses' power.

Note X. Friction of Rope on the Brunton and Shields Railway.

By observation, seven empty waggons took down rope in 3′ 45″ (= $8\frac{4}{10}$ miles per hour), which makes friction ...... $88\frac{3}{4}$ lbs.
Mr. Thompson says 8 waggons take it down in 3 minutes (= $10\frac{1}{2}$ miles per hour), which gives friction .... 82 „

Average friction.................. $85\frac{1}{2}$ lbs.

Weight of rope = 1861 lbs. $\div 85\frac{1}{2} = 22$, or say friction of rope, sheaves, barrel, brake, &c. = $\frac{1}{22}$ of weight of rope.

Killingworth.—16 empty waggons descended Killingworth plane in 4 minutes with $4\frac{1}{4}$ inch rope after them, of which the weight was 3096 lbs. Inclination of plane 1 in $62\frac{1}{2}$. This leaves for friction of rope, &c. $143\frac{1}{2}$ lbs., or say $\frac{1}{22}$ of weight nearly.

Note Y. Rope on Brusselton Plane.

1851 yards—inclination 1 in $33\frac{1}{2}$—ascended with load.
825 yards— „ 1 in $30\frac{1}{2}$—descended with load.

Average taken at 1 in 33, which gives 69 lbs.=gravity of 1 ton.

$$\left.\begin{array}{r} 1851 \times (69 + 12\frac{1}{2}) \times 1.5 = 226{,}284 \\ 825 \times (69 - 12\frac{1}{2}) \times 1.5 = 69{,}919 \end{array}\right\} \text{loaded.} \quad (\text{Tons.})$$

$$\left.\begin{array}{r} 825 \times (69 + 12\frac{1}{2}) \times .5 = 33{,}618 \\ 1851 \times (69 - 12\frac{1}{2}) \times .5 = 52{,}292 \end{array}\right\} \text{empty.}$$

$$382{,}113 \div 12\frac{1}{2} = 30.569$$

$$30.569 \div 1760 = 17.37$$
$$\text{Deduct....}\tfrac{1}{3} = 5.79$$
$$11.58, \text{ say } 11\tfrac{1}{2}$$

$11\frac{1}{2}$ miles: 1 mile: : .25d, : .0243 of a penny.

Note I. Horse's Power.

At 2½ miles per hour, a good horse will, upon a good road, go 20 miles per day with [illegible] cwt. including the carriage. The effect per day is therefore [illegible] cwt. x 20 miles ...[illegible] cwt. moved one mile.

At 6 miles per hour in the short stages round London, a lighter horse of nearly the same value will go 16 miles with 17½ cwt. say coach [illegible] cwt., passengers [illegible] cwt., and packages [illegible] cwt. equal to 17½ cwt. x 16 miles ....[illegible] cwt. moved one mile.

At 10 miles a still lighter horse will not do more than 16 miles per day in a mail coach with [illegible] cwt. say coach [illegible] cwt., passengers [illegible] cwt., bags and parcels 5 cwt. = [illegible] cwt. say [illegible] cwt. ÷ 4 = [illegible] cwt. x 16 miles....[illegible] cwt. moved one mile.

Therefore at 2½ miles per hour the horse does the work of [illegible] horses at 6 miles, and of [illegible] horses at 10 miles per hour; besides at the high speed, the horse will not last half the time he will at the low speed.

Note A 2. Engines for Liverpool Tunnel.

1970 yards long-rise 1 in 48. lbs.

Gravity = 2240 ÷ 48 = ... 46.66

Friction = 2240 ÷ 150 = ... 12.44

Together.............. 59.10 lbs = resistance of one ton

Goods and waggons............ 52 tons

Rope 7 inches = 6¾ lbs. per yard = 5½ „

Together.............. 57½ tons, total weight to be raised

Deduct ⅓ of 52 tons = .. 17½ tons, descending empty waggons

Leaves...... 40 tons preponderance

40 tons x 59.10 lbs. resistance	2364 lbs.
17.5 + 17.5 = 35 tons, ascending and descending waggons.. 35 x 12.44 = ...	435.4 „
	2799.4 lbs.
Gravity of rope = 5.5. tons x 46.66 = ...	256.6 „
Friction of rope = $\frac{1}{11}$ of 5½ tons = ...	597.0 „
	3653 lbs.